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Changes in morphological, thermal and pasting properties of yam (*Dioscorea alata*) starch during growth

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Abstract

This study was carried out in order to compare and establish the changes in physicochemical properties of starch from four different cultivars of yam at various stages of maturity during growth. The results showed that the starch content of the four yam tubers increased as growth progressed and were in the range of 70.5–85.3% on a dry basis. The shapes of the starch granules were round to oval or angular in the four yams and the size of starch granule increased with growth time ranging from 10 to 40 μm. The X-ray diffraction patterns could be classified as typical of B-type starch for the four cultivars of yam starch. The transition temperature of gelatinization of the four yam starches decreased during maturity. The RVA parameters suggested that yam starch paste showed a lower breakdown at an early harvest time. It appeared to be thermo-stable during heating but had a high setback after cooling, which might result in a tendency towards high retrogradation. The results for pasting behaviors showed that higher amylose content was associated with a lower pasting temperature and a higher peak viscosity in these starches.

Keywords: Growth period; Yam cultivars; Yam starch; Morphology; Thermal and pasting properties

1. Introduction

Yams (*Dioscorea alata* L.) are grown widely in tropical and subtropical regions of the world. They are plants yielding tubers and contains starch between 70 and 80% of dry matter (Kim, Wiesenborn, Orr, & Grant, 1995; Lauzon et al., 1995; Zhang & Oates, 1999). Yams, the edible tubers of various species of the genus *Dioscorea*, are important staple foods and a potential source of ingredients for fabricated foods in many tropical countries because of their high starch content. Starches are the major storage polysaccharides in root and tuber crops and such starches have a semi-crystalline structure. Root and tuber starches have unique physicochemical properties mostly due to their amylose and amylopectin ratio (Sievert & Wuesch, 1993; Jenkins & Donald, 1995). Cheetham & Tao (1997) reported that crystallinity decreased with increasing amylose content in maize starches. Matveev et al. (2001) concluded that the melting thermodynamic properties of starches were directly correlated to their amylose content. X-ray diffraction patterns have been used to reveal the characteristics of the crystalline structure of starch granules (Zobel, Young, & Rocca 1988). Most of the root and tuber starches exhibit a typical B-type X-ray pattern (Hoover, 2001).

Identification of native starch sources that have desired functionality and unique properties is needed (Duxbury, 1989). Among the most important functional properties of starches are their thermal and pasting properties. The thermal and pasting behaviors of starch are important to the evaluation and estimation of process design, unit operation and the quality of final starch-based products (Perez, Breene, & Bahnassey, 1998a,b). Pasting behavior is usually studied by observing changes in the viscosity of a starch system based on rheological principles. From the pasting curve, several parameters can be reported that indicate the extent of disintegration, and whether there is retrogradation. In general, root and tuber starches show weaker associative intragranular forces. Root and tuber starches gelatinize at relative low temperatures, with rapid and uniform swelling of granules. They also exhibit a high viscosity profile and a high paste clarity compared to cereal starches, although root and tuber starches retrograde easily (Craig, Maningat, Seib, & Hoseney, 1989). Liu, Weber, Currie, and Yada (2003) indicated that potato starch from tubers with a shorter growth time gave a smaller granule size, which contributed to a higher peak temperature of gelatinization.

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Yam starch has been reported as an alternative source because of several desirable properties of its starch, such as viscosity stability to high temperature and a low pH (Alves, Gressman, & Silva, 1999). However, the high retrogradation of yam starch gel is disadvantageous when it is applied to food systems. The starch properties of roots and tubers vary between different cultivars and with growth time. Christensen & Madsen (1996) reported that the starch granule size, peak viscosity and phosphorus content increased but amylose remained unchanged during potato growth. Madsen and Christensen (1996) found that the hot paste stability of potato starch decreased as potato tuber development increased. In order to understand the change in the physicochemical properties of yam starch during growth, four different local varieties of yam tubers were grown for 260 days. Yam was harvested each month after the 5th month of plant. The purpose of this study was to establish the functional characteristics of the isolated starches from these yams during growth. Yam starches were isolated and the physicochemical properties of the starches measured in terms of morphology, semi-crystalline structure, thermal properties and pasting properties.

2. Materials and methods

2.1. Materials

Yams (*Dioscorea alata* L.) were grown at a local farm (Nantou, Taiwan) in a fine sand soil. Four different cultivars (*TN1*, *TN2*, *Dasan*; and *Purpurea*) were used for this study. The plots were under 40 m^2 net and the seed tubers were planted on the 18th March, 2004. Yam tubers were harvested at four dates after planting, namely, at 155, 190, 225 and 260 days into the growing season. After harvest, the yam tubers were stored at 18 °C for 24 h before starch isolation. All chemicals were of ACS certified grade.

2.2. Starch preparation

Yam starches were extracted and purified using the procedure of Hoover and Hadzigev (1981). Yam tubers were rinsed, peeled, diced and then blended by a domestic blender in a sodium bisulfite water solution (750 mL/L). The mixture was then passed through a 200 mesh sieve. The residues were exhaustively rinsed with sodium bisulfite solution again. The filtrate was allowed to stand at 4 °C overnight. The precipitate was collected and the supernatant was discarded. The starch sediment was treated with 0.1% sodium hydroxide solution and then centrifuged at $6000\times g$. The precipitate was collected and rinsed several times with distilled water until the pH of starch was close to 7.0. The starch sediment was then rinsed with 70% ethanol. The precipitate was evaporated and dried in a conventional oven at 40 °C overnight. The starch was ground with a mortar and pestle to a size suitable to passing through a 200 mesh sieve. The powdered starch was collected and stored in a freezer with double bags of polyethylene.

2.3. Starch and amylose content

The starch content of the yam tubers was determined by AACC methods (1983). The starch content of yam tuber was calculated and expressed as a dry weight basis. Amylose content of isolated starches was expressed as apparent amylose and total amylose content using the method of McGrance, Cornell, and Rix, (1998) and Hoover and Ratnayake (2001).

2.4. Morphological properties

Scanning electron micrographs (SEM) were obtained using a Hitachi S-3000N scanning electron microscope (Hitachi Co., Tokyo, Japan). Starch samples were suspended in ethanol at 1%. One drop of the starch ethanol mixture was applied onto an aluminum stub using double-sided adhesive tape. The sample was coated with gold–palladium. An accelerating potential of 15 KV was used during electron micrography.

2.5. Particle size (Tecante & Doublier, 1999)

The particle sizes of the isolated starches were measured by using a Malvern Master Sizer (Malvern Instrument, Ltd, UK) laser diffraction analyzer in, at least, triplicate replicates at room temperature. The isolated starches were dispersed in distilled water at 4%. The instrument output had a volume distribution as the fundamental measurement, with medians of D[V, 0.1], D[V, 0.5], and D[V, 0.9] diameters. The output data D[V, 0.1], D[V, 0.5], D[V, 0.9] means that the diameter of the granules for which 10, 50, and 90% of the starch volume was made up of granules that were smaller. These derived output data are numerical transformations of diffracted light angles according to Mie's theory (Malvern Instruments Ltd, UK, 1990).

2.6. X-ray diffraction (McPherson & Jane, 1999; Yu, Fujii, & Kishihara, 1999)

X-ray diffraction of the starches were measured using a Siemens X-ray diffractometer (Model D5000, Siemens Co., Madison, USA) with the operating conditions set as follows: target voltage 40 kV, current 30 mA, scanning range (2θ) 4–30°, scan speed 0.02°/s, receiving slit width 0.2 nm.

2.7. Thermal properties (Kim, Wiesenborn, & Grant, 1997)

The thermal properties of the isolated starches were measured using a differential scanning calorimeter (DSC, Model 2910, TA Instruments Inc., New Castle, DE, USA). Starch (3 mg) and distilled water were loaded into an aluminum pan and hermetically sealed. The sample pans were allowed to stand for 2 h at room temperature in order to attain an even distribution of water before heating the calorimeter. An empty aluminum pan was used as reference and the calorimeter was calibrated with indium. The scanning temperature range was 20–120 °C at a heating rate of 10 °C/min. The onset (T_o), peak (T_p) and conclusion (T_c)

temperatures and enthalpy (ΔH) of gelatinization of the dry starch were calculated automatically.

2.8. Pasting properties (Deffenbaugh & Walker, 1989)

The pasting properties of isolated starches were investigated with a Rapid Visco-Analyzer (RVA 3D, Newport Scientific, Australia). An 8% starch–water suspension (28 g total weight) was prepared and treated with a heating–cooling cycle. The starch suspensions were equilibrated at 50 °C for 2 min, heated from 50 to 95 °C at a heating rate of 6 °C/min, then held at 95 °C for 6 min. Afterwards the paste was cooled to 50 °C at 6 °C/min and kept at 50 °C for 6 min. Paddle speed was set at 160 rpm in this analysis. The viscoamylogram described the various characteristics of the starch including peak temperature, peak viscosity (P), viscosity at 95 °C after 6 min holding (H), and final viscosity at end of 50 °C holding period (F). Other parameters including setback and breakdown were calculated from the above viscoamylogram characteristics. The unit of pasting properties of yam starch is expressed as RVU, where RVU is the unit of viscosity from the Rapid Visco Analyzer. Three replicates of each sample were carried out.

2.9. Statistical analysis

The mean values and standard deviations of each analysis are reported. Analysis of variance (ANOVA) was performed as part of the data analyses (SAS, 1988). When F-values were significant ($p<0.05$) in ANOVA, then least significant differences (LSD) were calculated to compare treatment means.

3. Results and discussion

3.1. Starch and amylose content

Yam tubers have been used as a good source of staple food in tropical regions. Yam tubers contain high proportions of starch and, as well as being used for food, are well suited to use as ingredients in fabricated foods. Dry matter and starch content of plant origin act as important indicators for quality evaluation of starchy food products (Lisinska & Leszczynski, 1989; Treche & Agbor-Egbe, 1996). The starch and amylose content of the various yam tubers at different development times are presented in Table 1. The major constituent of yam tubers is starch ranging between 81.8–85.3% on a dry basis at the final harvest time (Table 1). The results also show that the starch content of yam tubers varied across the yam cultivars and with the growth period (Table 1). The starch content of the yams significantly increased with growth time in all cultivars ($p<0.05$), with the most significant increase over the earliest stages of growth time (155–225 days). Starch content ranged from 74.1 to 82.9%, and after that increased slightly as growth progressed, with the exception of *Purpurea* tubers. Over the 260-day development period, *Purpurea* tubers gave the highest starch content at 260 days growth time. Several studies related to the optimum harvesting time have reported on the growth of

Table 1
Starch and amylose content of different yam tubers during growth

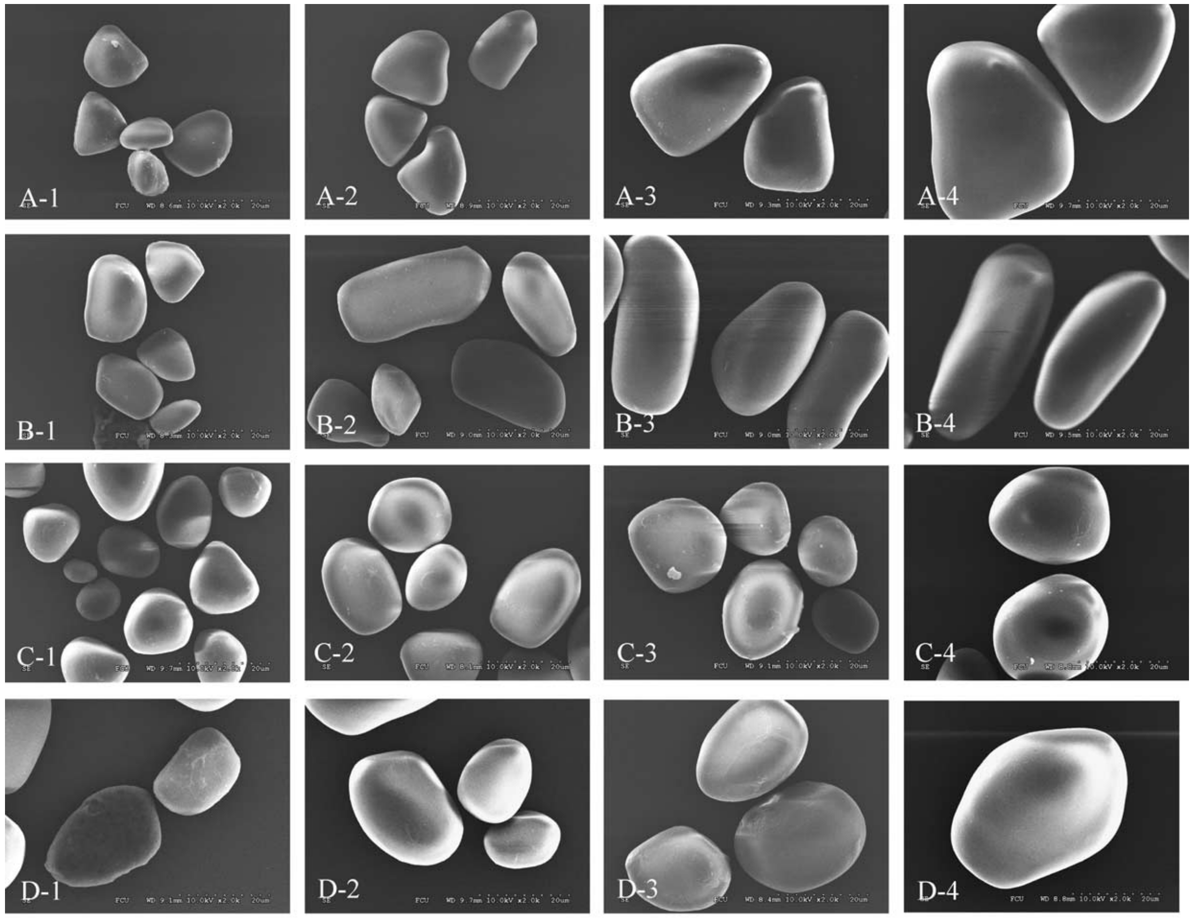
Yam cultivars	Growth time (days)	Starch (%)[a]	Amylose content[b]	
			Apparent	Total
TN1	155	74.5[e]	36.5[e]	37.8[e]
	190	76.6[d]	36.1[e]	37.9[e]
	225	81.1[c]	38.1[d]	39.3[d]
	260	81.8[c]	39.0[c]	40.1[c]
TN2	155	74.1[e]	30.4[d]	32.1[d]
	190	78.7[d]	23.5[e]	24.9[f]
	225	81.7[c]	24.8[e]	26.1[e]
	260	82.2[c]	31.9[c]	33.1[c]
Dasan	155	80.7[d]	32.4[c]	33.9[c]
	190	81.0[d]	29.4[d]	30.9[e]
	225	82.9[c]	30.9[d]	32.7[d]
	260	83.3[c]	32.4[c]	33.5[c]
Purpurea	155	70.5[f]	31.6[c]	33.1[c]
	190	75.0[e]	30.5[d]	31.9[d]
	225	77.3[d]	28.5[e]	29.5[e]
	260	85.3[c]	31.6[c]	32.8[c]

[a] Starch content of different yam cultivars were calculated on the basis of dry matter.
[b] Apparent and total amylose determined by I_2-binding before and after removal of bound lipids, respectively.
[c–f] Means with different letters within the same column and the same cultivar differ significantly ($p<0.05$).

Dioscorea alata tubers (Noda, Takahata, Sato, Hisamatsu, & Yamada, 1995; Treche & Agbor-Egbe,1996) and according to their results, this time is judged to be the optimum time for harvesting based on starch content. It is noteworthy that the maximum amylose content of yam starch was observed in *TN1* yam starch with values of 39% for apparent amylose and 40.1% for total amylose content. Compared to other yam starches, the *TN2* and *Purpurea* yam starches gave a lower amylose content (31.6–31.9% and 32.8–33.1%) at final harvest time in this experiment.

3.2. Morphological characteristics and particle size

The morphological granular characteristics of yam starch granules are presented in Fig. 1. The shape of isolated yam starch granules appeared large and oval with a diameter between 20 and 40 μm (Fig. 1). The results of SEM showed that the shape of the yam starches appear similarly during maturation with the exception of *TN2* starch. The shape of *TN1* yam starch granules has been observed from angular-shape to conic shape during maturation. The *Dasan* and *Purpurea* starches have similar shapes from the micrographs and appear to be oval to pentagonal shape as growth progressed. However, the apparent shape of *TN2* starches changes remarkably throughout growth period. The small olivary shape is exhibited at earlier development stages (155 days) and become large rectangle shape at later stages of growth (225–260 days) for *TN2* starch granules. Compared to other root and tuber starches, yam starches appeared to have a larger granular size than most similar starches in the previous reports (Hoover, 2001; Liu et al., 2003; McPherson & Jane, 1999; Shannon & Garwood, 1984). The particle size measurement of the yam



* ——— : **bar length is 20 μm in these micrographs; 15kv accelerating potential**

Fig. 1. Scanning electron microscopy of four cultivars yam straches (A, B, C, and D are representative of *Dioscorea alata* var. *TN1*, var. *TN2*, var, *Dasan*, and var. *Purpurea*, respectively), during growth (1, 2, 3, and representative of 155, 190, 225 and 260 days, respectively), (bar in each picture is 20 μm).

starches were carried out using laser diffraction analyzer. The laser diffraction results are expressed at 10, 50, and 90% diameter for starch size. The results of particle size from laser diffraction agreed with the results from the scanning electron micrographs. The granular size distributions of the four isolated starches at different development stages are summarized in Table 2. The size of the isolated starch granules increased with the growth period from 155 to 260 days in all yam cultivars. Our data is comparable with previous studies (Liu et al., 2003; Noda et al., 1995) where the size of starch granules becomes larger with increasing physiological plant age. The size of *Dasan* and *Purpurea* starches increased rapidly over the 155–190 days growth period; however, from190 to 225 days this was slight for *TN1* starch. *Purpurea* starch granules exhibited the largest granule size at 10, 50 and 90% diameter compared to the other starches according to the laser diffraction results. The smallest granule size for starch was found for *Dasan* starch.

3.3. X-ray pattern

X-ray diffractometry has been widely used to reveal the characteristics of the crystalline structure of starch granules (Zobel et al., 1988). Imberty Chanzy, Perez, Buleon, and Tran (1988) proposed that both A- and B-type starches were identical with double helices, but that the A-type starch was more closely packed. Most of root and tuber starches show a typical B-type X-ray diffraction pattern (Zobel et al., 1988) with four main reflection intensities at 5.5°, 17°, 22°, and 23.5° 2θ angles. The X-ray powder diffraction patterns of isolated starches derived from yam tubers as a function of their development stages are shown in Fig. 2 (due to similarity in the patterns for all yam starches, only *Dasan* starch is presented). The profiles of the yam starches from the various cultivars at different physiological ages all show the four distinctive peaks at 5.5° (peak 1), 17° (peak 4a), 22° (peak 6a) and 23.5° (peak 6b) (2θ), but yam starches do give a very sharp and high peak of 17° (2θ) supporting a typical B-type X-ray patterns. Previous studies indicated that the semi-crystalline structure of sweet potato and potato starches is not strongly influenced by growth time (Liu et al., 2003; Noda et al., 1995) and this agrees with our findings. According to the X-ray patterns (Fig. 2), the lowest peak intensity at peak 6a and 6b was observed on 155 days. As growth time progressed, the peak intensity of peak 6a and 6b were increased with the increase of growth

Table 2
Granule diameter value of different yam starches during growth

Yam cultivars	Growth time (days)	Granules diameter of yam starches (μm)				
		D (4, 3)[a]	D (3, 2)[b]	D (V, 0.1)[c]	D (V, 0.5)[d]	D (V, 0.9)[e]
TN1	155	22.73±0.19	9.77±0.18	8.79±0.08	21.34±0.15	38.81±0.39
	190	24.04±0.37	11.17±0.13	11.43±0.14	23.27±0.27	38.57±0.77
	225	28.09±0.10	14.04±1.18	15.41±0.09	27.64±0.09	42.96±0.23
	260	29.89±0.18	11.67±0.06	13.39±0.04	25.81±0.13	43.17±0.43
TN2	155	21.32±0.61	8.95±0.17	9.03±0.16	20.31±0.98	36.18±1.40
	190	23.22±0.10	9.95±0.03	11.52±0.02	22.23±0.05	37.45±0.25
	225	25.93±0.23	11.21±0.06	13.32±0.03	24.84±0.15	41.46±0.53
	260	28.03±0.12	11.98±0.02	14.61±0.03	26.80±0.05	44.71±0.34
Dasan	155	19.02±0.93	8.17±0.31	9.28±0.06	18.89±0.20	30.49±1.37
	190	23.75±0.39	9.36±0.03	11.50±0.13	21.91±0.06	38.67±0.96
	225	19.68±0.05	8.22±0.01	10.87±0.01	19.46±0.03	29.90±0.16
	260	22.84±0.06	9.77±0.37	12.00±0.14	22.06±0.03	36.04±0.33
Purpurea	155	25.15±0.20	12.17±0.06	14.20±1.15	24.86±0.16	38.30±0.40
	190	27.69±0.04	12.28±0.02	15±0.02	26.91±0.03	42.99±0.09
	225	28.49±0.03	12.54±0.01	16.13±0.01	27.94±0.01	43.37±0.06
	260	28.04±0.06	12.94±0.01	15.04±0.02	27.56±0.05	43.03±0.14

Mean±Standard deviation ($n=3$).
[a] D [4, 3] granule diameter derived from the volume distribution.
[b] D [3, 2] ratio of volume of particles to the total surface area.
[c] D [V, 0.1] median of 10% granule diameter (μm).
[d] D [V, 0.5] median of 50% granule diameter (μm).
[e] D [V, 0.9] median of 90% granule diameter (μm).

time. Thus, the peak intensities of X-ray diffraction patterns increased slightly with increased growth time. However, there is need for more information on starch crystallinity in order to determine the relationship between the semi-crystalline structure and growth period (Fig. 3).

3.4. Thermal properties

The DSC thermal properties of starch suspension for all starches are summarized in Table 3. All starches showed a single symmetrical endotherm during gelatinization. All yam starches from different cultivars and growth time showed a similar tendency in the thermograms (Table 3). All the parameters of gelatinization temperatures (T_o, T_p, T_c) from the different yam cultivars decreased significantly with increased growth time ($p<0.05$). The same phenomenon was found for gelatinization temperature in potato starch during growth, as demonstrated by Liu et al. (2003). As the gelatinization temperature reflects the degree of orderly arrangement of the molecules in the starch granule, it may be assumed that yam starch at earlier development stage (155 days) are more ordered than at the later stage of development. Of the four starches, *Dasan* yam starches had the highest peak temperature for gelatinization (Table 3). No significant difference ($p>0.05$) was observed for the physiological age of same yam cultivar with regards to range of gelatinization temperature except *TN2* starch at 155 days. The gelatinization enthalpy of yam starches increased slightly with the development stage

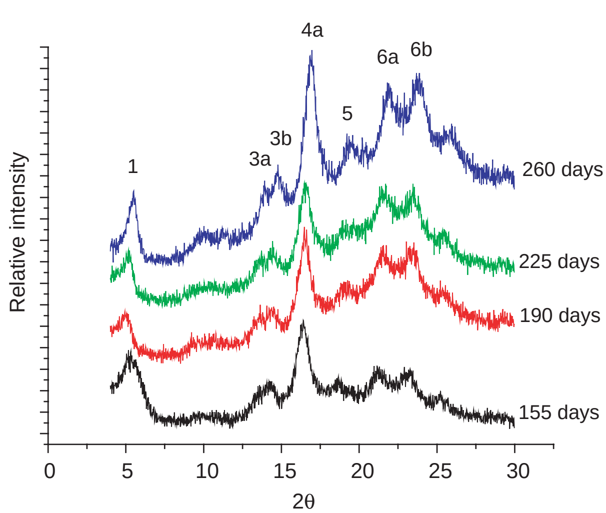


Fig. 2. A typical of X-ray diffraction pattern of yam (*Dioscorea alata* var. *Dasan*) straches during growth.

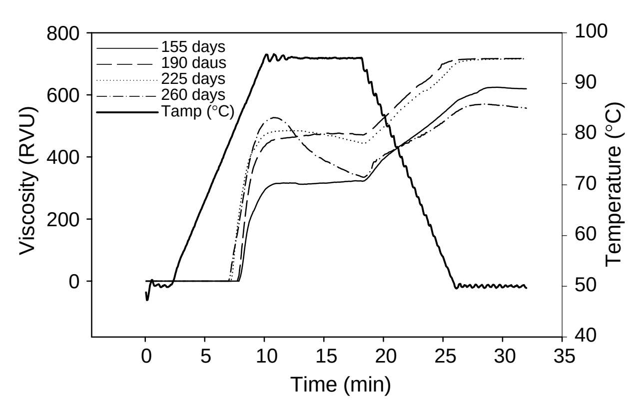


Fig. 3. A typical RVA pasting curves of yam (*Dioscorea alata* var. *Dasan*) strach during growth.

Table 3
Gelatinization properties of yam starches during growth measured by differential scanning calorimetry (DSC)

Yam cultivars	Growth time (days)	Parameters of endothermic properties[a]				
		T_o (°C)	T_p (°C)	T_c (°C)	Gelatinization range (°C)	ΔH (J/g)
TN1	155	75.8±0.3	81.6±0.1	87.8±1.0	12.0	15.7[c]
	190	73.7±0.6	78.8±0.1	84.8±1.1	11.1	15.6[c]
	225	70.0±0.3	74.5±0.1	80.9±0.8	10.9	16.8[b]
	260	68.8±0.8	73.5±0.1	79.9±0.1	11.1	11.8[d]
TN2	155	73.9±1.5	81.4±0.1	88.4±0.6	14.5	16.7[c]
	190	72.8±0.6	78.3±0.1	84.3±0.7	11.5	17.5[b]
	225	71.1±0.3	76.1±0.1	83.6±0.8	12.5	17.9[b]
	260	69.3±0.4	75.1±0.1	81.0±0.7	11.7	14.7[d]
Dasan	155	75.7±0.8	82.4±0.3	88.3±0.3	12.6	16.7[c]
	190	74.8±0.7	80.4±0.1	86.3±0.7	11.5	15.9[d]
	225	72.3±0.5	77.7±0.1	84.4±0.5	12.1	18.0[b]
	260	71.6±0.3	76.0±0.1	83.4±0.6	11.8	14.7[e]
Purpurea	155	75.0±0.7	80.6±0.1	86.7±0.6	11.7	14.3[d]
	190	73.7±0.8	78.4±0.1	84.4±0.7	10.7	14.7[c,d]
	225	72.0±0.7	77.0±0.1	84.0±0.5	12.0	16.3[b]
	260	72.2±0.2	77.3±0.1	83.7±0.7	11.5	15.0[c]

[a] T_o = onset temperature; T_p = peak temperature; T_c = closed temperature; ΔH = enthalpy (J/g starch); Gelatinization range (°C) = ($T_c - T_o$).
[b–e] Means with different letters within the same column and same cultivars differ significantly ($p<0.05$).

(155–225 days) and then decreased rapidly to the lowest enthalpy at final harvest (260 days).

3.5. Pasting properties

As starch granules are heated with sufficient water, the starch suspension swell markedly and the viscosity of the system increases dramatically. The pasting behaviors of yam starches as measured by a Rapid Visco–Analyzer are given in Table 4. According to the RVA patterns, the pasting behaviors of yam starches were greatly affected by growth time. Yam starches at 155 days gave the highest pasting temperature (82.2 °C) in all four cultivars. The results also show that the pasting temperature of yam starches decreased with increased growth time. The peak viscosity of starch paste is an important characteristic to distinguish a given starch from the other species of starch. For the four cultivars, the peak viscosity for pasting behavior of the yam starches increased as yam growth time increased. For starch at the longest growth time (260 days) for the four yam starches, the peak viscosity was in the range 494.7–708.9 RVU and this was between 50 and 120% higher than that of the shortest growth time. Several pieces of research have shown the same tendency for pasting temperature and peak viscosity to be present in sweet potato starch and potato

Table 4
Pasting properties of yam starches during growth measured by rapid visco analyzer

Yam cultivar	Growth time (days)	Parameters of pasting behaviors[a]					
		Pasting temperature (°C)	Peak viscosity (P)	Viscosity after 95 °C holding (H)	Final viscosity after 50 °C holding (F)	Breakdown (P–H)	Setback (F–H)
TN1	155	81.2[b]	217.6[e]	203.6[e]	394.8[c]	14.0	191.2
	190	80.3[b]	309.2[d]	290.7[d]	623.4[b]	18.5	332.7
	225	75.1[c]	480.4[c]	380.2[b]	598.3[c]	100.1	218.1
	260	76.3[c]	494.7[b]	324.1[c]	507.5[d]	170.5	183.3
TN2	155	81.9[b]	299.6[e]	300.0[e]	567.4[c]	−0.4	267.4
	190	79.7[c]	462.4[d]	327.6[d]	585.7[b]	134.7	258.1
	225	76.8[d]	572.4[c]	479.0[b]	579.3[b]	93.3	100.3
	260	77.0[d]	708.9[b]	399.0[c]	461.7[d]	369.9	62.7
Dasan	155	82.2[b]	310.2[e]	305.5[e]	613.2[c]	4.75	307.7
	190	81.9[b]	460.3[d]	460.4[b]	710.7[b]	−0.1	250.3
	225	78.9[c]	478.9[c]	437.5[c]	709.5[b]	41.4	272.0
	260	78.0[c]	520.4[b]	328.1[d]	550.5[d]	192.3	222.3
Purpurea	155	81.7[b]	327.1[e]	276.0[e]	612.7[b]	51.1	336.7
	190	79.9[c]	542.9[d]	325.7[c]	576.0[c]	178.4	250.3
	225	78.5[c]	606.3[b]	298.9[d]	548.5[d]	307.4	249.6
	260	79.9[c]	562.9[c]	350.6[b]	555.7[d]	212.3	205.1

[a] The unit of pasting properties of yam starch is expressed as RVU, where RVU is the unit of viscosity from the Rapid Visco Analyzer.
[b–e] Means with different letters within the same column and the same cultivar differ significantly ($p<0.05$) ($n=3$).

starch during growth (Liu et al., 2003; Noda et al., 1995). Liu et al. (2003) also indicated that potato starch with a shorter growth time resulted in smaller size of granules, which contribute to the higher pasting temperature and lower peak viscosity. As the temperature reached and was held at 95 °C, the paste viscosity of yam starches decreased markedly due to stirrer shearing. In contrast to commercial potato starch (Hoover, 2001), yam starches showed a very low level of breakdown compared to other starches with thermo-stable starch pastes at an early harvest time (155 days). As growth time progressed, yam starches began to show significant changes in breakdown. Yam starch at the earlier harvest time (155 days) showed a higher pasting temperature and thermal stability than starch at a later harvest time (225 days to 260 days), which suggests the presence of strong binding forces within the interior of the yam starch granules at the earlier harvest time. When the temperature was cooled to 50 °C, a sharp rise in final viscosity of starch paste was observed in all yam starches and harvest times. During the cooling cycle, the viscosity of all starch pastes increased rapidly because of the large number of intermolecular hydrogen bonds that were formed, resulting in gel formation at lower temperatures (Leelavathi, Indrani, & Sidhu, 1987). Yam starches gave a higher setback indicating a higher retrogradation tendency. This was most likely due to the greater amount of amylose present, which resulted in the shorter amylose chains causing intermolecular association, thus producing retrogradation (Hoover and Sosulski, 1991). Comparing the different physiological ages of yam starches, the setback of the starch paste decreased as growth time increased in the four yam cultivars.

4. Conclusions

The yam starch and amylose content of yam tubers rose during the growth period of 155–260 days. The particle size of the yam starches increased but the temperature transition of the thermograms decreased as growth progressed in all yam cultivars. The RVA results suggested that yam starch paste appeared to be thermo-stable during heating but showed a high setback after cooling, which resulted in a high retrogradation tendency. This study provides useful information in terms of changes in the X-ray diffraction patterns and thermograms as well as pasting behaviors of yam starches that will affect choice of harvest time and help in the evaluation of the potential uses of yam starch in value added products. The results obtained suggest that the optimum harvest time varies across the four cultivars of yam tubers and seems to be between 225 and 260 days after planting, depending on the physicochemical properties of the yam cultivars.

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